SKETCH OF A COURSE

OF

CHEMICAL PHILOSOPHY

BY

STANISLAO CANNIZZARO

(1858)

Alembic Club Reprints,
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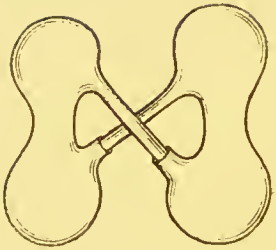

PREFACE

THE value of the hypothesis of the Italian physicist Avogadro* as a systematising principle in chemistry was practically unrecognised for forty years after its publication. It had been, it is true, considered and in part applied by Dumas, Gerhardt, and others, but the young Italian chemist Cannizzaro was the first to show its consistent applicability to the selection of atomic weights, and to harmonise with it the results of other methods directed towards the same end.

The eminence of Cannizzaro as a teacher is plain in every page of the summary of his lecture course on chemical philosophy which is here translated. The facts are marshalled and their bearing explained with absolute mastery of pedagogic method, and one is impelled to the conclusion that Cannizzaro's students of 1858 must have had clearer conceptions of chemical theory than most of his scientific colleagues of a much later date.

Permission to publish this translation was received from the venerable chemist a few days before his death on 10th May 1910.

J. W.

* Alembic Club Reprint, No. 4, p. 28.

LETTER OF
PROFESSOR STANISLAO CANNIZZARO
TO
PROFESSOR S. DE LUCA:

SKETCH OF A COURSE OF CHEMICAL PHILOSOPHY

*Given in the Royal University of Genoa.**

I BELIEVE that the progress of science made in these last years has confirmed the hypothesis of Avogadro, of Ampère, and of Dumas on the similar constitution of substances in the gaseous state; that is, that equal volumes of these substances, whether simple or compound, contain an equal number of molecules: not however an equal number of atoms, since the molecules of the different substances, or those of the same substance in its different states, may contain a different number of atoms, whether of the same or of diverse nature.

In order to lead my students to the conviction which I have reached myself, I wish to place them on the same path as that by which I have arrived at it—the path, that is, of the historical examination of chemical theories.

I commence, then, in the first lecture by showing how, from the examination of the physical properties

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* From *Il Nuovo Cimento*, vol. vii. (1858), pp. 321-366.

of gaseous bodies, and from the law of Gay-Lussac on the volume relations between components and compounds, there arose almost spontaneously the hypothesis alluded to above, which was first of all enunciated by Avogadro, and shortly afterwards by Ampère. Analysing the conception of these two physicists, I show that it contains nothing contradictory to known facts, provided that we distinguish, as they did, molecules from atoms; provided that we do not confuse the criteria by which the number and the weight of the former are compared, with the criteria which serve to deduce the weight of the latter; provided that, finally, we have not fixed in our minds the prejudice that whilst the molecules of compound substances may consist of different numbers of atoms, the molecules of the various simple substances must all contain either one atom, or at least an equal number of atoms.

In the second lecture I set myself the task of investigating the reasons why this hypothesis of Avogadro and Ampère was not immediately accepted by the majority of chemists. I therefore expound rapidly the work and the ideas of those who examined the relationships of the reacting quantities of substances without concerning themselves with the volumes which these substances occupy in the gaseous state; and I pause to explain the ideas of Berzelius, by the influence of which the hypothesis above cited appeared to chemists out of harmony with the facts.

I examine the order of the ideas of Berzelius, and show how on the one hand he developed and completed the dualistic theory of Lavoisier by his own electro-chemical hypothesis, and how on the other hand, influenced by the atomic theory of Dalton (which

had been confirmed by the experiments of Wollaston), he applied this theory and took it for his guide in his later researches, bringing it into agreement with the dualistic electro-chemical theory, whilst at the same time he extended the laws of Richter and tried to harmonise them with the results of Proust. I bring out clearly the reason why he was led to assume that the atoms, whilst separate in simple bodies, should unite to form the atoms of a compound of the first order, and these in turn, uniting in simple proportions, should form composite atoms of the second order, and why (since he could not admit that when two substances give a single compound, a molecule of the one and a molecule of the other, instead of uniting to form a single molecule, should change into two molecules of the same nature) he could not accept the hypothesis of Avogadro and of Ampère, which in many cases leads to the conclusion just indicated.

I then show how Berzelius, being unable to escape from his own dualistic ideas, and yet wishing to explain the simple relations discovered by Gay-Lussac between the volumes of gaseous compounds and their gaseous components, was led to formulate a hypothesis very different from that of Avogadro and of Ampère, namely, that equal volumes of simple substances in the gaseous state contain the same number of atoms, which in combination unite intact; how, later, the vapour densities of many simple substances having been determined, he had to restrict this hypothesis by saying that only simple substances which are permanent gases obey this law; how, not believing that composite atoms even of the same order could be equidistant in the gaseous state under the same conditions, he was led to suppose that in the molecules of hydrochloric, hydriodic, and hydrobromic

acids, and in those of water and sulphuretted hydrogen, there was contained the same quantity of hydrogen, although the different behaviour of these compounds confirmed the deductions from the hypothesis of Avogadro and of Ampère.

I conclude this lecture by showing that we have only to distinguish atoms from molecules in order to reconcile all the experimental results known to Berzelius, and have no need to assume any difference in constitution between permanent and coercible, or between simple and compound gases, in contradiction to the physical properties of all elastic fluids.

In the third lecture I pass in review the various researches of physicists on gaseous bodies, and show that all the new researches from Gay-Lussac to Clausius confirm the hypothesis of Avogadro and of Ampère that the distances between the molecules, so long as they remain in the gaseous state, do not depend on their nature, nor on their mass, nor on the number of atoms they contain, but only on their temperature and on the pressure to which they are subjected.

In the fourth lecture I pass under review the chemical theories since Berzelius: I pause to examine how Dumas, inclining to the idea of Ampère, had habituated chemists who busied themselves with *organic substances* to apply this idea in determining the molecular weights of compounds; and what were the reasons which had stopped him half way in the application of this theory. I then expound, in continuation of this, two different methods—the one due to Berzelius, the other to Ampère and Dumas—which were used to determine formulæ in inorganic and in organic chemistry respectively until Laurent and Gerhardt

sought to bring both parts of the science into harmony. I explain clearly how the discoveries made by Gerhardt, Williamson, Hofmann, Wurtz, Berthelot, Frankland, and others, on the constitution of organic compounds confirm the hypothesis of Avogadro and Ampère, and how that part of Gerhardt's theory which corresponds best with the facts and best explains their connection, is nothing but the extension of Ampère's theory, that is, its complete application, already begun by Dumas.

I draw attention, however, to the fact that Gerhardt did not always consistently follow the theory which had given him such fertile results ; since he assumed that equal volumes of gaseous bodies contain the same number of molecules, only in the majority of cases, but not always.

I show how he was constrained by a prejudice, the reverse of that of Berzelius, frequently to distort the facts. Whilst Berzelius, on the one hand, did not admit that the molecules of simple substances could be divided in the act of combination, Gerhardt supposes that all the molecules of simple substances are divisible in chemical action. This prejudice forces him to suppose that the molecule of mercury and of all the metals consists of two atoms, like that of hydrogen, and therefore that the compounds of all the metals are of the same type as those of hydrogen. This error even yet persists in the minds of chemists, and has prevented them from discovering amongst the metals the existence of biatomic radicals perfectly analogous to those lately discovered by Wurtz in organic chemistry.

From the historical examination of chemical theories, as well as from physical researches, I draw the conclusion that to bring into harmony all the branches of

chemistry we must have recourse to the complete application of the theory of Avogadro and Ampère in order to compare the weights and the numbers of the molecules; and I propose in the sequel to show that the conclusions drawn from it are invariably in accordance with all physical and chemical laws hitherto discovered.

I begin in the fifth lecture by applying the hypothesis of Avogadro and Ampère to determine the weights of molecules even before their composition is known.

On the basis of the hypothesis cited above, the weights of the molecules are proportional to the densities of the substances in the gaseous state. If we wish the densities of vapours to express the weights of the molecules, it is expedient to refer them all to the density of a simple gas taken as unity, rather than to the weight of a mixture of two gases such as air.

Hydrogen being the lightest gas, we may take it as the unit to which we refer the densities of other gaseous bodies, which in such a case express the weights of the molecules compared to the weight of the molecule of hydrogen = 1.

Since I prefer to take as common unit for the weights of the molecules and for their fractions, the weight of a half and not of a whole molecule of hydrogen, I therefore refer the densities of the various gaseous bodies to that of hydrogen = 2. If the densities are referred to air = 1, it is sufficient to multiply by 14.438 to change them to those referred to that of hydrogen = 1; and by 28·87 to refer them to the density of hydrogen = 2.

I write the two series of numbers, expressing these weights in the following manner :—

Names of Substances.	Densities or weights of one volume, the volume of Hydrogen being made = 1, *i.e.*, weights of the molecules referred to the weight of a whole molecule of Hydrogen taken as unity.	Densities referred to that of Hydrogen = 2, *i.e.*, weights of the molecules referred to the weight of half a molecule of Hydrogen taken as unity.
Hydrogen . . .	1	2
Oxygen, ordinary . .	16	32
Oxygen, electrised .	64	128
Sulphur below 1000° .	96	192
Sulphur* above 1000° .	32	64
Chlorine . . .	35·5	71
Bromine . . .	80	160
Arsenic . . .	150	300
Mercury . . .	100	200
Water	9	18
Hydrochloric Acid .	18·25	36·50†
Acetic Acid . . .	30	60

* This determination was made by Bineau, but I believe it requires confirmation.

† The numbers expressing the densities are approximate: we arrive at a closer approximation by comparing them with those derived from chemical data, and bringing the two into harmony.

Whoever wishes to refer the densities to hydrogen = 1 and the weights of the molecules to the weight of half a molecule of hydrogen, can say that the weights of the molecules are all represented by the weight of two volumes.

I myself, however, for simplicity of exposition, prefer to refer the densities to that of hydrogen = 2, and so the weights of the molecules are all represented by the weight of one volume.

From the few examples contained in the table, I show that the same substance in its different allotropic states can have different molecular weights, without concealing the fact that the experimental data on which this conclusion is founded still require confirmation.

I assume that the study of the various compounds has been begun by determining the weights of the molecules, *i.e.*, their densities in the gaseous state, without enquiring if they are simple or compound.

I then come to the examination of the composition of these molecules. If the substance is undecomposable, we are forced to admit that its molecule is entirely made up by the weight of one and the same kind of matter. If the body is composite, its elementary analysis is made, and thus we discover the constant relations between the weights of its components: then the weight of the molecule is divided into parts proportional to the numbers expressing the relative weights of the components, and thus we obtain the quantities of these components contained in the molecule of the compound, referred to the same unit as that to which we refer the weights of all the molecules. By this method I have constructed the following table :—

Name of Substance.	Weight of one volume, *i.e.*, weight of the molecule referred to the weight of half a molecule of Hydrogen = 1.	Component weights of one volume, *i.e.*, component weights of the molecule, all referred to the weight of half a molecule of Hydrogen = 1.	
Hydrogen . .	2	2 Hydrogen	
Oxygen, ordinary .	32	32 Oxygen	
,, electrised .	128	128 ,,	
Sulphur below 1000° .	192	192 Sulphur	
,, above 1000° (?)	64	64 ,,	
Phosphorus . .	124	124 Phosphorus	
Chlorine . . .	71	71 Chlorine	
Bromine . . .	160	160 Bromine	
Iodine . . .	254	254 Iodine	
Nitrogen . . .	28	28 Nitrogen	
Arsenic . . .	300	300 Arsenic	
Mercury . . .	200	200 Mercury	
Hydrochloric Acid .	36·5	35·5 Chlorine	1 Hydrogen
Hydrobromic Acid .	81	80 Bromine	1 ,,
Hydriodic Acid .	128	127 Iodine	1 ,,
Water . . .	18	16 Oxygen	2 ,,
Ammonia . . .	17	14 Nitrogen	3 ,,
Arseniuretted Hyd. .	78	75 Arsenic	3 ,,
Phosphuretted Hyd. .	35	32 Phosphorus	3 ,,
Calomel . . .	235·5	35·5 Chlorine	200 Mercury
Corrosive Sublimate .	271	71 ,,	200 ,,
Arsenic Trichloride .	181·5	106·5 ,,	75 Arsenic
Protochloride of Phosphorus . . .	138·5	106·5 ,,	32 Phosphorus
Perchloride of Iron .	325	213 ,,	112 Iron
Protoxide of Nitrogen	44	16 Oxygen	28 Nitrogen
Binoxide of Nitrogen	30	16 ,,	14 ,,
Carbonic Oxide .	28	16 ,,	12 Carbon
,, Acid . .	44	32 ,,	12 ,,
Ethylene . . .	28	4 Hydrogen	24 ,,
Propylene . .	42	6 ,,	36 ,,
Acetic Acid, hydrated	60	4 ,, 32 Oxygen 24 Carbon	
,, anhydrous .	102	6 Hydrogen 48 Oxygen 48 Carbon	
Alcohol . . .	46	6 Hydrogen 16 Oxygen 24 Carbon	
Ether . . .	74	10 Hydrogen 16 Oxygen 48 Carbon	

All the numbers contained in the preceding table are comparable amongst themselves, being referred to the same unit. And to fix this well in the minds of my pupils, I have recourse to a very simple artifice: I say to them, namely, "Suppose it to be shown that the half molecule of hydrogen weighs a millionth of a milligram, then all the numbers of the preceding table become concrete numbers, expressing in millionths of a milligram the concrete weights of the molecules and of their components: the same thing would follow if the common unit had any other concrete value," and so I lead them to gain a clear conception of the comparability of these numbers, whatever be the concrete value of the common unit.

Once this artifice has served its purpose, I hasten to destroy it by explaining how it is not possible in reality to know the concrete value of this unit; but the clear ideas remain in the minds of my pupils whatever may be their degree of mathematical knowledge. I proceed pretty much as engineers do when they destroy the wooden scaffolding which has served them to construct their bridges, as soon as these can support themselves. But I fear that you will say, "Is it worth the trouble and the waste of time and ink to tell me of this very common artifice?" I am, however, constrained to tell you that I have paused to do so because I have become attached to this pedagogic expedient, having had such great success with it amongst my pupils, and thus I recommend it to all those who, like myself, must teach chemistry to youths not well accustomed to the comparison of quantities.

Once my students have become familar with the importance of the numbers as they are exhibited in the preceding table, it is easy to lead them to discover

the law which results from their comparison. "Compare," I say to them, "the various quantities of the same element contained in the molecule of the free substance and in those of all its different compounds, and you will not be able to escape the following law: *The different quantities of the same element contained in different molecules are all whole multiples of one and the same quantity, which, always being entire, has the right to be called an atom.*"

Thus:—

One molecule	of free hydrogen .	contains	2	of hydrogen	= 2 × 1
,,	of hydrochloric acid .	,,	1	,,	= 1 × 1
,,	of hydrobromic acid	,,	1	,,	= 1 × 1
,,	of hydriodic acid .	,,	1	,,	= 1 × 1
,,	of hydrocyanic acid .	,,	1	,,	= 1 × 1
,,	of water . . .	,,	2	,,	= 2 × 1
,,	of sulphuretted hydrogen . .	,,	2	,,	= 2 × 1
,,	of formic acid . .	,,	2	,,	= 2 × 1
,,	of ammonia . .	,,	3	,,	= 3 × 1
,,	of gaseous phosphuretted hydrogen .	,,	3	,,	= 3 × 1
,,	of acetic acid . .	,,	4	,,	= 4 × 1
,,	of ethylene . .	,,	4	,,	= 4 × 1
,,	of alcohol . .	,,	6	,,	= 6 × 1
,,	of ether . . .	,,	10	,,	= 10 × 1

Thus all the various weights of hydrogen contained in the different molecules are integral multiples of the weight contained in the molecule of hydrochloric acid, which justifies our having taken it as common unit of the weights of the atoms and of the molecules. The atom of hydrogen is contained twice in the molecule of free hydrogen.

In the same way it is shown that the various quantities of chlorine existing in different molecules are all whole multiples of the quantity contained in the molecule of hydrochloric acid, that is, of 35.5; and

that the quantities of oxygen existing in the different molecules are all whole multiples of the quantity contained in the molecule of water, that is, of 16, which quantity is half of that contained in the molecule of free oxygen, and an eighth part of that contained in the molecule of electrised oxygen (ozone).

Thus :—

One molecule	of free oxygen	. contains	32	of oxygen	= 2 × 16
,,	of ozone . .	,,	128	,,	= 8 × 16
,,	of water . .	,,	16	,,	= 1 × 16
,,	of ether . . .	,,	16	,,	= 1 × 16
,,	of acetic acid .	,,	32	,,	= 2 × 16
	etc. etc.				

One molecule	of free chlorine .	contains	71	of chlorine	= 2 × 35·5
,,	of hydrochloric acid	,,	35·5	,,	= 1 × 35·5
,,	of corrosive sublimate	,,	71	,,	= 2 × 35·5
,,	of chloride of arsenic	,,	106·5	,,	= 3 × 35·5
,,	of chloride of tin .	,,	142	,,	= 4 × 35·5
	etc. etc.				

In a similar way may be found the smallest quantity of each element which enters as a whole into the molecules which contain it, and to which may be given with reason the name of atom. In order, then, to find the atomic weight of each element, it is necessary first of all to know the weights of all or of the greater part of the molecules in which it is contained and their composition.

If it should appear to any one that this method of finding the weights of the molecules is too hypothetical, then let him compare the composition of equal volumes of substances in the gaseous state under the same conditions. He will not be able to escape the following law: *The various quantities of the same element contained in equal volumes either of the free element or of its compounds are all whole multiples of one and the same quantity;* that is, each element has a special

numerical value by means of which and of integral coefficients the composition by weight of equal volumes of the different substances in which it is contained may be expressed. Now, since all chemical reactions take place between equal volumes, or integral multiples of them, it is possible to express all chemical reactions by means of the same numerical values and integral coefficients. The law enunciated in the form just indicated is a direct deduction from the facts: but who is not led to assume from this same law that the weights of equal volumes represent the molecular weights, although other proofs are wanting? I thus prefer to substitute in the expression of the law the word molecule instead of volume. This is advantageous for teaching, because, when the vapour densities cannot be determined, recourse is had to other means for deducing the weights of the molecules of compounds. The whole substance of my course consists in this: to prove the exactness of these latter methods by showing that they lead to the same results as the vapour density when both kinds of method can be adopted at the same time for determining molecular weights.

The law above enunciated, called by me the law of atoms, contains in itself that of multiple proportions and that of simple relations between the volumes; which I demonstrate amply in my lecture. After this I easily succeed in explaining how, expressing by symbols the different atomic weights of the various elements, it is possible to express by means of formulæ the composition of their molecules and of those of their compounds, and I pause a little to make my pupils familiar with the passage from gaseous volume to molecule, the first directly expressing the fact and the second interpreting it. Above all, I study to

implant in their minds thoroughly the difference between molecule and atom. It is possible indeed to know the atomic weight of an element without knowing its molecular weight; this is seen in the case of carbon. A great number of the compounds of this substance being volatile, the weights of the molecules and their composition may be compared, and it is seen that the quantities of carbon which they contain are all integral multiples of 12, which quantity is thus the atom of carbon and expressed by the symbol C; but since we cannot determine the vapour density of free carbon we have no means of knowing the weight of its molecule, and thus we cannot know how many times the atom is contained in it. Analogy does not in any way help us, because we observe that the molecules of the most closely analogous substances (such as sulphur and oxygen), and even the molecules of the same substance in its allotropic states, are composed of different numbers of atoms. We have no means of predicting the vapour density of carbon; the only thing that we can say is that it will be either 12 or an integral multiple of 12 (in my system of numbers). The number which is given in different treatises on chemistry as the theoretical density of carbon is quite arbitrary, and a useless datum in chemical calculations; it is useless for calculating and verifying the weights of the molecules of the various compounds of carbon, because the weight of the molecule of free carbon may be ignored if we know the weights of the molecules of all its compounds; it is useless for determining the weight of the atom of carbon, because this is deduced by comparing the composition of a certain number of molecules containing carbon, and the knowledge of the weight of the molecule of this last would scarcely add a datum more

to those which are already sufficient for the solution of the problem. Any one will easily convince himself of this by placing in the following manner the numbers expressing the molecular weights derived from the densities and the weights of the components contained in them :—

Names of Compounds of Carbon.	Weights of the molecules referred to the atom of Hydrogen.	Weights of the components of the molecules referred to the weight of the atom of Hydrogen taken as unity.	Formulæ, making H = 1 C = 12 O = 16 S = 32
Carbonic Oxide .	28	12 Carbon 16 Oxygen	CO
,, Acid .	44	12 ,, 32 ,,	CO^2
Sulphide of Carbon	76	12 ,, 64 Sulphur	CS^2
Marsh Gas . .	16	12 ,, 4 Hydrogen	CH^4
Ethylene . .	28	24 ,, 4 ,,	C^2H^4
Propylene . .	42	36 ,, 6 ,,	C^3H^6
Ether . . .	74	{48 ,, 10 ,, 16 Oxygen}	$C^4H^{10}O$
etc.	etc.	etc.	etc.

In the list of molecules containing carbon there might be placed also that of free carbon if the weight of it were known ; but this would not have any greater utility than what we would derive by writing in the list one more compound of carbon ; that is, it would do nothing but verify once more that the quantity of carbon contained in any molecule, whether of the element itself or of its compounds, is 12 or $n \times 12 = C^n$, n being an integral number.

I then discuss whether it is better to express the composition of the molecules of compounds as a function of the molecules of the components, or if, on the other hand, it is better, as I commenced by doing, to express the composition of both in terms of those constant quantities which always enter by whole numbers into both, that is, by means of the atoms.

Thus, for example, is it better to indicate in the formula that one molecule of hydrochloric acid contains the weight of half a molecule of hydrogen and half a molecule of chlorine, or that it contains an atom of one and an atom of the other, pointing out at the same time that the molecules of both of these substances consist of two atoms?

Should we adopt the formulæ made with symbols indicating the molecules of the elements, then many coefficients of these symbols would be fractional, and the formula of a compound would indicate directly the ratio of the volumes occupied by the components and by the compounds in the gaseous state. This was proposed by Dumas in his classical memoir, *Sur quelques points de la Théorie atomique* (Annales de Chimie et de Physique, tom. 33, 1826).

To discuss the question proposed, I give to the molecules of the elements symbols of a different kind from those employed to represent the atoms, and in this way I compare the formulæ made with the two kinds of symbols.

Atoms or Molecules.	Symbols of the molecules of the Elements and formulæ made with these symbols.	Symbols of the atoms of the Elements and formulæ made with these symbols.	Nos. expressing their weights.
Atom of Hydrogen . . .	$\mathfrak{H}\frac{1}{2}$	= H =	1
Molecule of Hydrogen . .	$\mathfrak{H}$	= H^2 =	2
Atom of Oxygen . . .	$\mathfrak{O}\frac{1}{2} = \mathfrak{O}\mathfrak{z}\frac{1}{8}$	= O =	16
Molecule of ordinary Oxygen .	$\mathfrak{O}$	= O^2 =	32
Molecule of electrised Oxygen (Ozone)	$\mathfrak{O}\mathfrak{z}$	= O^8 =	128
Atom of Sulphur . . .	$\mathfrak{S}\frac{1}{2} = \mathfrak{S}\mathfrak{a}\frac{1}{6}$	= S =	32
Molecule of Sulphur above 1000° (Bineau)	$\mathfrak{S}$	= S^2 =	64
Molecule of Sulphur below 1000°	$\mathfrak{S}\mathfrak{a}$	= S^6 =	192
,, Water . . .	$\mathfrak{H}\mathfrak{O}\frac{1}{2} = \mathfrak{H}\mathfrak{O}\mathfrak{z}\frac{1}{8}$	= H^2O =	18
,, Sulphuretted Hydrogen	$\mathfrak{H}\mathfrak{S}\frac{1}{2} = \mathfrak{H}\mathfrak{S}\mathfrak{a}\frac{1}{6}$	= H^2S =	34

These few examples are sufficient to demonstrate the inconveniences associated with the formulæ indicating the composition of compound molecules as a function of the entire component molecules, which may be summed up as follows :—

1°. It is not possible to determine the weight of the molecules of many elements the density of which in the gaseous state cannot be ascertained.

2°. If it is true that oxygen and sulphur have different densities in their different allotropic states, that is, if they have different molecular weights, then their compounds would have two or more formulæ according as the quantities of their components were referred to the molecules of one or the other allotropic state.

3°. The molecules of analogous substances (such as sulphur and oxygen) being composed of different numbers of atoms, the formulæ of analogous compounds would be dissimilar. If we indicate, instead, the composition of the molecules by means of the atoms, it is seen that analogous compounds contain in their molecules an equal number of atoms.

It is true that when we employ in the formulæ the symbols expressing the weights of the molecules, *i.e.*, of equal volumes, the relationship between the volumes of the components and those of the compounds follows directly ; but this relationship is also indicated in the formulæ expressing the number of atoms ; it is sufficient to bear in mind that the atom represented by a symbol is either the entire molecule of the free substance or a fraction of it, that is, it is sufficient to know the atomic formula of the free molecule. Thus, to take an example, it is sufficient to know that the atom of oxygen, O, is one-half of the molecule of ordinary oxygen and an eighth part of the molecule of electrised oxygen—to know that the weight of the atom of

oxygen is represented by $\frac{1}{2}$ volume of free oxygen and $\frac{1}{8}$ of electrised oxygen. In short, it is easy to accustom students to consider the weights of the atoms as being represented either by a whole volume or by a fraction of a volume, according as the atom is equal to the whole molecule or to a fraction of it. In this system of formulæ, those which represent the weights and the composition of the molecules, whether of elements or of compounds, represent the weights and the composition of equal gaseous volumes under the same conditions. The atom of each element is represented by that quantity of it which constantly enters as a whole into equal volumes of the free substance or of its compounds ; it may be either the entire quantity contained in one volume of the free substance or a simple sub-multiple of this quantity.

This foundation of the atomic theory having been laid, I begin in the following lecture—the sixth—to examine the constitution of the molecules of the chlorides, bromides, and iodides. Since the greater part of these are volatile, and since we know their densities in the gaseous state, there cannot remain any doubt as to the approximate weights of the molecules, and so of the quantities of chlorine, bromine, and iodine contained in them. These quantities being always integral multiples of the weights of chlorine, bromine, and iodine contained in hydrochloric, hydrobromic, and hydriodic acids, *i.e.*, of the weights of the half molecules, there can remain no doubt as to the atomic weights of these substances, and thus as to the number of atoms existing in the molecules of their compounds, whose weights and composition are known.

A difficulty sometimes appears in deciding whether the quantity of the other element combined with one atom of these halogens is 1, 2, 3, or n atoms in the

molecule; to decide this, it is necessary to compare the composition of all the other molecules containing the same element and find out the weight of this element which constantly enters as a whole. When we cannot determine the vapour densities of the other compounds of the element whose atomic weight we wish to determine, it is necessary then to have recourse to other criteria to know the weights of their molecules and to deduce the weight of the atom of the element. What I am to expound in the sequel serves to teach my pupils the method of employing these other criteria to verify or to determine atomic weights and the composition of molecules. I begin by making them study the following table of some chlorides, bromides, and iodides whose vapour densities are known; I write their formulæ, certain of justifying later the value assigned to the atomic weights of some elements existing in the compounds indicated. I do not omit to draw their attention once more to the atomic weights of hydrogen, chlorine, bromine, and iodine being all equal to the weights of half a molecule, and represented by the weight of half a volume, which I indicate in the following table:—

	Symbol.	Weight.
Weight of the atom of Hydrogen or half a molecule represented by the weight of ½ volume .	H	1
Weight of the atom of Chlorine or half a molecule represented by the weight of ½ volume .	Cl	35·5
Weight of the atom of Bromine or half a molecule represented by the weight of ½ volume .	Br	80
Weight of the atom of Iodine or half a molecule represented by the weight of ½ volume .	I	127

These data being given, there follows the table of some compounds of the halogens:—

Names of the Chlorides.	Weights of equal volumes in the gaseous state, under the same conditions, referred to the weight of ½ volume of Hydrogen = 1; *i.e.*, weights of the molecules referred to the weight of the atom of Hydrogen = 1.	Composition of equal volumes in the gaseous state, under the same conditions, *i.e.*, composition of the molecules, the weights of the components being all referred to the weight of the atom of Hydrogen taken as unity, *i.e.*, the common unit adopted for the weights of atoms and of molecules.	Formulæ expressing the composition of the molecules or of equal volumes in the gaseous state under the same conditions.
Free Chlorine . . .	71	71 of Chlorine	Cl^2
Hydrochloric Acid . . .	36·5	35·5 ,, 1 of Hydrogen . . .	HCl
Protochloride of Mercury or Calomel	235·5	35·5 ,, 200 of Mercury . . .	$HgCl$
Bichloride of Mercury or Corrosive Sublimate . . .	271	71 ,, 200 ,, . . .	$HgCl^2$
Chloride of Ethyl . . .	64·5	35·5 ,, 5 of Hydrogen 24 of Carbon	C^2H^5Cl
,, Acetyl . . .	78·5	{ 35·5 ,, 3 ,, . . . 24 of Carbon 16 of Oxygen . . . }	C^2H^3OCl
,, Ethylene . .	99	71 of Chlorine 4 of Hydrogen 24 of Carbon	$C^2H^4Cl^2$
,, Arsenic . .	181·5	106·5 ,, 75 of Arsenic . . .	$AsCl^3$
Protochloride of Phosphorus .	138·5	106·5 ,, 32 of Phosphorus . . .	PCl^3
Chloride of Boron . . .	117·5	106·5 ,, 11 of Boron	BCl^3
Bichloride of Tin . . .	259·6	142 ,, 117·6 of Tin	$SnCl^4$
,, Titanium . .	198	142 ,, 56 of Titanium . . .	$TiCl^4$
Chloride of Silicon . . .	170	142 ,, 28 of Silicon	$SiCl^4$
,, Zirconium . .	231	142 ,, 89 of Zirconium . . .	$ZrCl^4$
,, Aluminium . .	267	213 ,, 54 of Aluminium . . .	Al^2Cl^6
Perchloride of Iron . . .	325	213 ,, 112 of Iron	Fe^2Cl^6
Sesquichloride of Chromium .	319	213 ,, 106 of Chromium . . .	Cr^2Cl^6

I stop to examine the composition of the molecules of the two chlorides and the two iodides of mercury. There can remain no doubt that the protochloride contains in its molecule the same quantity of chlorine as hydrochloric acid, that the bichloride contains twice as much, and that the quantity of mercury contained in the molecules of both is the same. The supposition made by some chemists that the quantities of chlorine contained in the two molecules are equal, and on the other hand that the quantities of mercury are different, is supported by no valid reason. The vapour densities of the two chlorides having been determined, and it having been observed that equal volumes of them contain the same quantity of mercury, and that the quantity of chlorine contained in one volume of the vapour of calomel is equal to that contained in the same volume of hydrochloric acid gas under the same conditions, whilst the quantity of chlorine contained in one volume of corrosive sublimate is twice that contained in an equal volume of calomel or of hydrochloric acid gas, the relative molecular composition of the two chlorides cannot be doubtful. The same may be said of the two iodides. Does the constant quantity of mercury existing in the molecules of these compounds, and represented by the number 200, correspond to one or more atoms? The observation that in these compounds the same quantity of mercury is combined with one or two atoms of chlorine or of iodine, would itself incline us to believe that this quantity is that which enters always as a whole into all the molecules containing mercury, namely, the atom; whence $Hg = 200$.

To verify this, it would be necessary to compare the various quantities of mercury contained in all the molecules of its compounds whose weights and

composition are known with certainty. Few other compounds of mercury besides those indicated above lend themselves to this; still there are some in organic chemistry the formulæ of which express well the molecular composition; in these formulæ we always find $Hg^2 = 200$, chemists having made $Hg = 100$ and $H = 1$. This is a confirmation that the atom of mercury is 200 and not 100, no compound of mercury existing whose molecule contains less than this quantity of it. For verification I refer to the law of the specific heats of elements and of compounds.

I call the quantity of heat consumed by the atoms or the molecules the product of their weights into their specific heats. I compare the heat consumed by the atom of mercury with that consumed by the atoms of iodine and of bromine in the same physical state, and find them almost equal, which confirms the accuracy of the relation between the atomic weight of mercury and that of each of the two halogens, and thus also, indirectly, between the atomic weight of mercury and that of hydrogen, whose specific heats cannot be directly compared.

Thus we have—

Name of Substance.	Atomic weight.	Specific heat, *i.e.*, heat required to heat unit weight 1°.	Products of specific heats by atomic weights, *i.e.*, heat required to heat the atom 1°.
Solid Bromine .	80	0·08432	6·74560
Iodine . .	127	0·05412	6·87324
Solid Mercury .	200	0·03241	6·48200

The same thing is shown by comparing the specific heats of the different compounds of mercury. Woestyn and Garnier have shown that the state of combination does not notably change the calorific

capacity of the atoms; and since this is almost equal in the various elements, the molecules would require, to heat them 1°, quantities of heat proportional to the number of atoms which they contain. If Hg = 200, that is, if the formulæ of the two chlorides and iodides of mercury are HgCl, HgI, $HgCl^2$, HgI^2, it will be necessary that the molecules of the first pair should consume twice as much heat as each separate atom, and those of the second pair three times as much; and this is so in fact, as may be seen in the following table:—

Formulæ of the compounds of Mercury.	Weights of their molecules $=p$.	Specific heats of unit weight $=c$.	Specific heats of the molecules $=p \times c$.	Number of atoms in the molecules $=n$.	Specific heats of each atom $=\frac{p \times c}{n}$.
HgCl .	235·5	0·05205	12·257745	2	6·128872
HgI .	327	0·03949	12·91323	2	6·45661
$HgCl^2$.	271	0·06889	18·66919	3	6·22306
HgI^2 .	454	0·04197	19·05438	3	6·35146

Thus the weight 200 of mercury, whether as an element or in its compounds, requires to heat it 1° the same quantity of heat as 127 of iodine, 80 of bromine, and almost certainly as 35·5 of chlorine and 1 of hydrogen, if it were possible to compare these two last substances in the same physical state as that in which the specific heats of the above-named substances have been compared.

But the atoms of hydrogen, iodine, and bromine are half their respective molecules: thus it is natural to ask if the weight 200 of mercury also corresponds to half a molecule of free mercury. It is sufficient to look at the table of numbers expressing the molecular weights to perceive that if 2 is the molecular weight of hydrogen, the weight of the molecule of mercury is

200, *i.e.*, equal to the weight of the atom. In other words, one volume of vapour, whether of protochloride or protoiodide, whether of bichloride or of biniodide, contains an equal volume of mercury vapour; so that each molecule of these compounds contains an entire molecule of mercury, which, entering as a whole into all the molecules, is the atom of this substance. This is confirmed by observing that the complete molecule of mercury requires for heating it 1°, the same quantity of heat as half a molecule of iodine, or half a molecule of bromine. It appears to me, then, that I can sustain that what enters into chemical actions is the half molecule of hydrogen and the whole molecule of mercury: both of these quantities are indivisible, at least *in the sphere of chemical actions actually known.* You will perceive that with this last expression I avoid the question if it is possible to divide this quantity further. I do not fail to apprise you that all those who faithfully applied the theory of Avogadro and of Ampère, have arrived at this same result. First Dumas and afterwards Gaudin showed that the molecule of mercury, differing from that of hydrogen, always entered as a whole into compounds. On this account Gaudin called the molecule of mercury monatomic, and that of hydrogen biatomic. However, I wish to avoid the use of these adjectives in this special sense, because to-day they are employed as you know in a very different sense, that is, to indicate the different capacity for saturation of the radicals.

The formulæ of the two chlorides of mercury having been demonstrated, I next compare them with that of hydrochloric acid. The atomic formulæ indicate that the constitution of the protochloride is similar to that of hydrochloric acid, if we consider the number of atoms existing in the molecules of the two; if,

however, we compare the quantities of the components with those which exist in their free molecules, then a difference is perceived. To make this evident I bring the atomic formulæ of the various molecules under examination into comparison with the formulæ made with the symbols expressing the weights of the entire molecules, placing them in the manner which you see below :—

	Symbols of the molecules of the elements and formulæ of their compounds made with these symbols, *i.e.*, symbols and formulæ representing the weights of equal volumes in the gaseous state.	Symbols of the atoms of the elements, and formulæ of their compounds made with these symbols.	Numbers expressing the corresponding weights.
Atom of Hydrogen . . .	$\mathfrak{H}\frac{1}{2}$ =	H =	1
Molecule of Hydrogen . .	$\mathfrak{H}$ =	H^2 =	2
Atom of Chlorine . . .	$\mathfrak{Cl}\frac{1}{2}$ =	Cl =	35·5
Molecule of Chlorine . .	$\mathfrak{Cl}$ =	Cl^2 =	71
Atom of Bromine . . .	$\mathfrak{Br}\frac{1}{2}$ =	Br =	80
Molecule of Bromine . .	$\mathfrak{Br}$ =	Br^2 =	160
Atom of Iodine . . .	$\mathfrak{I}\frac{1}{2}$ =	I =	127
Molecule of Iodine . . .	$\mathfrak{I}$ =	I^2 =	254
Atom of Mercury . . .	$\mathfrak{Hg}$ =	Hg =	200
Molecule of Mercury . .	$\mathfrak{Hg}$ =	Hg =	200
,, Hydrochloric Acid	$\mathfrak{H}\frac{1}{2}\mathfrak{Cl}\frac{1}{2}$ =	HCl =	36·5
,, Hydrobromic Acid	$\mathfrak{H}\frac{1}{2}\mathfrak{Br}\frac{1}{2}$ =	HBr =	81
,, Hydriodic Acid .	$\mathfrak{H}\frac{1}{2}\mathfrak{I}\frac{1}{2}$ =	HI =	128
Mol. of protochloride of Mercury	$\mathfrak{Hg}\mathfrak{Cl}\frac{1}{2}$ =	HgCl =	235·5
,, protobromide of Mercury	$\mathfrak{Hg}\mathfrak{Br}\frac{1}{2}$ =	HgBr =	280
,, protoiodide of Mercury .	$\mathfrak{Hg}\mathfrak{I}\frac{1}{2}$ =	HgI =	327
,, bichloride of Mercury .	$\mathfrak{Hg}\mathfrak{Cl}$ =	$HgCl^2$ =	271
,, bibromide of Mercury .	$\mathfrak{Hg}\mathfrak{Br}$ =	$HgBr^2$ =	360
,, biniodide of Mercury .	$\mathfrak{Hg}\mathfrak{I}$ =	HgI_2 =	454

The comparison of these formulæ confirms still more the preference which we must give to the atomic formulæ, which indicate also clearly the

relations between the gaseous bodies. It is sufficient to recall that whilst the atoms of chlorine, bromine, iodine, and hydrogen are represented by the weight of $\frac{1}{2}$ volume, the atom of mercury is represented by the weight of a whole volume.

I then come to the examination of the two chlorides of copper. The analogy with those of mercury forces us to admit that they have a similar atomic constitution, but we cannot verify this directly by determining and comparing the weights and the compositions of the molecules, as we do not know the vapour densities of these two compounds.

The specific heats of free copper and of its compounds confirm the atomic constitution of the two chlorides of copper deduced from the analogy with those of mercury. Indeed the composition of the two chlorides leads us to conclude that if they have the formulæ $CuCl$, $CuCl^2$, the atomic weight of copper indicated by Cu is equal to 63, which may be seen from the following proportions :—

	Ratio between the components expressed by numbers whose sum = 100.	Ratio between the components expressed by atomic weights.
Protochloride of Copper .	36·04 : 63·96 Chlorine. Copper.	35·5 : 63 Cl. Cu.
Bichloride of Copper .	52·98 : 47·02 Chlorine. Copper.	71 : 63 Cl^2. Cu.

Now 63 multiplied by the specific heat of copper gives a product practically equal to that given by the atomic weight of iodine or of mercury into their respective specific heats. Thus:

$$\underset{\text{Atomic weight of copper.}}{63} \times \underset{\text{Specific heat of copper.}}{0{\cdot}09515} = 6$$

The same quantity of heat is required to heat the weight of 63 of copper in its compounds through 1°. Thus :—

Formulæ of the compounds of Copper.	Weights of their molecules $=p$.	Specific heats of unit weights $=c$.	Specific heats of the molecules $=p \times c$.	Number of atoms in the molecules $=n$.	Specific heat of each atom $=\frac{p \times c}{n}$.
CuCl .	98·5	0·13827	13·619595	2	6·809797
CuI .	190	0·06869	14·0511	2	7·0255

After this comes the question, whether this quantity of copper which enters as a whole into the compounds, the calorific capacity of the atoms being maintained, is an entire molecule or a sub-multiple of it. The analogy of the compounds of copper with those of mercury would make us inclined to believe that the atom of copper is a complete molecule. But having no other proof to confirm this, I prefer to declare that there is no means of knowing the molecular weight of free copper until the vapour density of this substance can be determined.

I then go on to examine the constitution of the chlorides, bromides, and iodides of potassium, sodium, lithium, and silver. Each of these metals makes with each of the halogens only one well characterised and definite compound ; of none of these compounds is the vapour density known ; we are therefore in want of the direct means of discovering if in their molecules there are one, two, or more atoms of the halogens. But their analogies with the protochloride of mercury, HgCl, and with the protochloride of copper, CuCl, and the specific heats of the free metals and of their compounds make us assume that in the molecules of each of these compounds there is one atom of metal

and one of halogen. According to this supposition, the atomic weight of potassium K = 39, that of sodium Na = 23, that of silver Ag = 108. These numbers multiplied by the respective specific heats give the same product as the atomic weights of the substances previously examined.

Name of Substance.	Atomic weight $=p$.	Specific heats of unit weight $=s$.	Specific heats of the atoms $=p \times c$.
Solid Bromine .	80	0·08432	6·74560
Iodine . .	127	0·05412	6·87324
Solid Mercury .	200	0·03241	6·48200
Copper . .	63	0·09515	6
Potassium . .	39	0·169556	6·612684
Sodium . .	23	0·2934	6·7482
Silver . .	108	0·05701	6·15708

Besides this, the specific heats of the chlorides, bromides, and iodides of these metals confirm the view that their molecules contain the same number of atoms of the two components. Thus :—

Formulæ and Names of the compounds.	Weights of their molecules $=p$.	Specific heats of unit weight $=c$.	Specific heats of the molecules $=p \times c$.	No. of atoms in the molecules $=n$	Specific heat of each atom $=\frac{p \times c}{n}$.
KCl . Chl. of Potassium.	74·5	0·17295	12·884775	2	6·442387
NaCl . Chl. of Sodium.	58·5	0·21401	12·519585	2	6·259792
AgCl . Chl. of Silver.	143·5	0·09109	13·071415	2	6·535707
KBr . Brom. of Potassium	119	0·11321	13·47318	2	6·73659
NaBr . Brom. of Sodium.	103	0·13842	14·25726	2	7·12863
AgBr . Brom. of Silver.	188	0·07391	13·89508	2	6·94754
KI . . Iod. of Potassium.	166	0·08191	13·59706	2	6·79853
NaI . . Iodide of Sodium.	150	0.08684	13·0260	2	6·5130
AgI . . Iodide of Silver.	235	0·06159	14·47365	2	7·23682

Are the atoms of potassium, sodium, lithium, and silver equal to $\frac{1}{2}$ molecule, like that of hydrogen, or equal to a whole molecule, like that of mercury? As the vapour densities of these elements are wanting, we cannot answer the question directly; I will give you later some reasons which incline me to believe that the molecules of these elements, like that of hydrogen, are composed of two atoms.

Gold makes with each of the halogens two compounds. I show that the first chloride is analogous to calomel, *i.e.*, that it has AuCl as it formula. The atomic weight of gold deduced from the composition of the protochloride to which this formula is given corresponds to the law of specific heats, as may be seen from what follows:

$$\underset{\text{Au}}{196{\cdot}32} \times \underset{\text{Specific heat of Gold.}}{0{\cdot}03244} = 6{\cdot}3696208$$

I show in the sequel that the first or only chlorides of the following metals have a constitution similar to the bichloride of mercury and of that of copper, that is, for each atom of metal they contain two atoms of chlorine.

Not knowing the density in the gaseous state of these lower or only chlorides, we cannot show directly the quantity of chlorine existing in their molecules, yet the specific heats of these free metals and of their compounds show what I have said above. I write the quantities of these different elements combined with the weight of two atoms of chlorine in the lower or only chlorides, and confirm in these quantities the properties of the other atoms; I write the formulæ of the lower chlorides, bromides, and iodides all as MCl^2, and verify that they

correspond to the laws of specific heats of compound substances.

Names of Substances.	Symbols and weights of the atoms.	Specific heats of unit weight.	Specific heats of the atoms.
Iodine . .	I = 127	0·05412	6·87324
Solid Mercury	Hg = 200	0·03241	6·48200
Copper . .	Cu = 63	0·09515	6
Zinc . .	Zn = 66	0·09555	6·30630
Lead . .	Pb = 207	0·0314	6·4998
Iron . .	Fe = 56	0·11379	6·37224
Manganese .	Mn = 55	0·1181	6·4955
Tin . .	Sn = 117·6	0·05623	6·612648
Platinum .	Pt = 197	0·03243	6·38871
Calcium . .	Ca = 40		
Magnesium .	Mg = 24		
Barium . .	Ba = 137		

Formulæ of the compounds.	Weights of their molecules $=p$.	Specific heats of unit weight $=c$.	Specific heats of the molecules $=p\times c$.	No. of atoms in the molecules $=n$.	Specific heat of each atom $=\frac{p\times c}{n}$.
$HgCl^2$.	271	0·06889	18·66919	3	6·22306
$ZnCl^2$.	134	0·13618	18·65666	3	6·21888
$SnCl^2$.	188·6	0·10161	19·163646	3	6·387882
$MnCl^2$.	126	0·14255	17·96130	3	5·98710
$PbCl^2$.	278	0·06641	18·46198	3	6·15399
$MgCl^2$.	95	0·1946	18·4870	3	6·1623
$CaCl^2$.	111	0·1642	18·2262	3	6·0754
$BaCl^2$.	208	0·08957	18·63056	3	6·21018
HgI^2 .	454	0·04197	19·05438	3	6·35146
PbI^2 .	461	0·04267	19·67087	3	6·55695

Some of the metals indicated above make other compounds with chlorine, bromine, and iodine, whose molecular weights may be determined and compositions compared ; in such cases the values found for the atomic weights are confirmed. Thus, for example, a

molecule of perchloride of tin weighs 259.6, and contains 117.6 of tin (=Sn) and 142 of chlorine ($=Cl^4$). A molecule of perchloride of iron weighs 325, and contains 112 of iron ($=Fe^2$) and 213 of chlorine ($=Cl^6$).

For zinc there are some volatile compounds which confirm the atomic weight fixed by me. Chemists believing chloride of zinc to be of the same type as hydrochloric acid, made the atom of zinc Zn = 33, that is half of that adopted by me; having then prepared some compounds of zinc with the alcohol radicals, they were astonished that, expressing the composition by formulæ corresponding to gaseous volumes equal to those of other well-known compounds, it was necessary to express the quantity of zinc contained in the molecule by Zn^2. This is a necessary consequence of the quantity of zinc represented by other chemists by Zn^2 being only a single atom, which is equivalent in its saturation capacity to two atoms of hydrogen. Since in the sequel of my lectures I return to this argument, you will therefore find it spoken of later in this abstract.

Are the atoms of all these metals equal to their molecules or to a simple sub-multiple of them? I gave you above the reasons which make me think it probable that the molecules of these metals are similar to that of mercury; but I warn you now that I do not believe my reasons to be of such value as to lead to that certainty which their vapour densities would give us if we only knew them.

Reviewing what I show in the lecture of which I have given you an abstract, we find it amounts to the following:—Not all the lower chlorides corresponding to the oxide with one atom of oxygen have the same constitution; some of them contain a single atom

of chlorine, others two, as may be seen in the following list :—

HCl	HgCl	CuCl	KCl	NaCl	LiCl	AgCl	AuCl
Hydrochloric acid.	Protochloride of mercury.	Protochloride of copper.	Chloride of potassium.	Chloride of sodium.	Chloride of lithium.	Chloride of silver.	Protochloride of gold.

$HgCl^2$	$CuCl^2$	$ZnCl^2$	$PbCl^2$	$CaCl^2$	$SnCl^2$	$PtCl^2$	etc. etc.
Bichloride of mercury.	Bichloride of copper.	Chloride of zinc.	Chloride of lead.	Chloride of calcium.	Protochloride of tin.	Protochloride of platinum.	

Regnault, having determined the specific heats of the metals and of many of their compounds, had observed that it was necessary to modify the atomic weights attributed to them, namely, to divide by 2 those of potassium, sodium, and silver, leaving the others unaltered ; or, *vice versa*, to multiply these latter by 2, leaving unaltered those of potassium, sodium, silver, and hydrogen. From this he drew the conclusion that the chlorides of potassium, sodium, and silver, are analogous to calomel (protochloride of mercury) and to protochloride of copper : on the other hand, that those of zinc, lead, calcium, etc., etc., are analogous to corrosive sublimate and to bichloride of copper ; but he supposed that the molecules of calomel and of the analogous chlorides all contained 2 atoms of metal and 2 of chlorine, whilst the molecules of corrosive sublimate and the other analogous chlorides contained 1 atom of metal and 2 of chlorine. Here follows the list of the formulæ proposed by Regnault.

H^2Cl^2	Hg^2Cl^2	Cu^2Cl^2	K^2Cl^2	Na^2Cl^2	Li^2Cl^2	Ag^2Cl^2	Au^2Cl^2
Hydrochloric acid.	Protochloride of mercury.	Protochloride of copper.	Chloride of potassium.	Chloride of sodium.	Chloride of lithium.	Chloride of silver.	Protochloride of gold.

$HgCl^2$	$CuCl^2$	$ZnCl^2$	$PbCl^2$	$CaCl^2$	etc.	etc.
Bichloride of mercury.	Bichloride of copper.	Chloride of zinc.	Chloride of lead.	Chloride of calcium.		

In truth, using the data for specific heats alone, it is not possible to decide whether the molecules of the chlorides written in the first horizontal line are MCl or M^2Cl^2; the only thing that can be said is that they contain the same number of atoms of metal and of chlorine. But knowing the densities in the gaseous state of hydrochloric acid and of the two chlorides of mercury, and thus the weights of their molecules, we can compare their composition and decide the question; and I have already explained to you how I show to my pupils that the molecules of the two chlorides of mercury contain the same weight of mercury, and that the molecule of one of them contains the same quantity of chlorine as hydrochloric acid, *i.e.*, $\frac{1}{2}$ molecule of free chlorine, whilst the molecule of the other chloride contains twice as much. This shows with certainty that the two formulæ Hg^2Cl^2, $HgCl^2$ are inexact, because they indicate that in the molecules of the two chlorides there is the same quantity of chlorine and different quantities of mercury, which is precisely the opposite of what is shown by the vapour densities. The formulæ proposed by me harmonise the results furnished by the specific heats and by the gaseous densities.

Now I wish to direct your attention to an inconsistency of Gerhardt. From the theory of Avogadro, Ampère, and Dumas, that is, from the comparison of the gaseous densities as representing the molecular weights, Gerhardt drew arguments in support of the view that the atoms of hydrogen, of chlorine, and of oxygen are half molecules; that the molecule of water contains twice as much hydrogen as that of hydrochloric acid; that in the molecule of ether there is twice as much of the radical ethyl as in that of alcohol; and that to form one molecule of anhydrous monobasic acid two

molecules of hydrated acid must come together: and yet Gerhardt did not extend to the whole of chemistry the theory of Ampère, but arbitrarily, in opposition to its precepts, assumed that the molecules of chloride of potassium, of bichloride of mercury, in fact of all the chlorides corresponding to the protoxides, had the same atomic constitution as hydrochloric acid, and that the atoms of all the metals were, like that of hydrogen, a simple sub-multiple of the molecule.

I have already explained to you the reasons which show the contrary.

After having demonstrated the constitution of the chlorides corresponding to the oxides containing one atom of oxygen, I postpone the study of the other chlorides to another lecture, and now define what I mean by capacity for saturation of the various metallic radicals.

If we compare the constitution of the two kinds of chlorides, we observe that one atom of metal is now combined with one atom of chlorine, now with two; I express this by saying that in the first case the atom of metal is equivalent to 1 of hydrogen, in the second case to 2. Thus, for example, the atom of mercury, as it is in calomel, is equivalent to 1 of hydrogen, whereas in corrosive sublimate it is equivalent to 2; the atoms of potassium, sodium, and silver are equivalent to 1 of hydrogen: the atoms of zinc, lead, magnesium, calcium, etc., to 2. Now it is seen from the study of all chemical actions that the number of atoms of the various substances which combine with one and the same quantity of chlorine combine also with one and the same quantity of oxygen, of sulphur, or of any other substance, and *vice versa*. Thus, for example, if the same quantity of chlorine which combines with a single atom of zinc, or lead,

or calcium combines with 2 atoms of hydrogen, of potassium, or of sodium, then the same quantity of oxygen or of any other substance which combines with a single atom of the first will combine with two of the second. This shows that the property possessed by the first atoms of being equivalent to 2 of the second depends on some cause inherent either in their own nature or in the state in which they are placed before combining. We express this constant equivalence by saying that each atom of the first has a saturation capacity twice that of each of the second. These expressions are not new to science, and we now only extend them from compounds of the second order to those of the first order.

For the same reasons given by chemists when they say that phosphoric acid assumes various saturation capacities without changing in composition, it may also be said that the atom of mercury and that of copper assume different saturation capacities according as they are found in the protochlorides or in the bichlorides. Thus, I express the fact that the atoms of these two metals being equivalent to 1 atom of hydrogen in the protochlorides, tend, in double decompositions, to take the place of a single atom of hydrogen, whilst in the bichlorides they tend to take the place of 2 atoms of hydrogen. For the same reason that we say there are three different modifications of phosphoric acid combined with various bases, we may also say that there are two different modifications of the same radical mercury or copper. I call the radicals of the protochlorides and of the corresponding salts, mercurous and cuprous; those of the bichlorides and of the corresponding salts are called mercuric and cupric radicals.

To express the various saturation capacities of the

different radicals, I compare them to that of hydrogen or of the halogens, according as they are electro-positive or electro-negative. An atom of hydrogen is saturated by one of a halogen, and *vice versa.* I express this by saying that the first is a monatomic electro-positive radical, and the second a monatomic electro-negative radical: thus, potassium, sodium, lithium, silver, and the mercurous and cuprous radicals are monatomic electro-positive radicals. The biatomic radicals are those which, not being divisible, are equivalent to 2 of hydrogen or to 2 of chlorine; among the electro-positive radicals there are the metallic radicals of the mercuric and cupric salts, of the salts of zinc, lead, magnesium, calcium, etc., and amongst the electro-negative we have oxygen, sulphur, selenium, and tellurium, *i.e.*, the amphidic substances. There are, besides, radicals which are equivalent to three or more atoms of hydrogen or of chlorine, but I postpone the study of these until later.

Before finishing the lecture I take care to make clear that the law of equivalents must be considered as a law distinct from the law of atoms.

The latter in fact only says that the quantities of the same element contained in different molecules must be integral multiples of one and the same quantity, but it does not predict, for example, that an atom of zinc is equivalent to 2 of hydrogen not only in its compounds with chlorine, but in all other compounds in which they may replace each other. These constant relations between the numbers of atoms of various substances which displace one another, whatever may be the nature and the number of the other components, is a law which restricts the number of possible combinations, and sums up with greater definiteness all the cases of double decomposition.

I occupy the whole of the seventh lecture in studying some monatomic and biatomic radicals, namely, cyanogen and the alcohol radicals.

I have already told you the method which I faithfully follow for ascertaining the weights and numbers of the molecules of the various substances whose vapour densities can be determined. This method, applied to all the substances which contain alcohol radicals, permits us, so to speak, to follow the path from one molecule to another. To discover the saturation capacity of a radical, it is expedient to begin with the examination of a molecule in which it is combined with a monatomic radical: thus for electro-negative radicals I begin by examining the compounds with hydrogen or with any other monatomic electro-positive radical; and conversely, for the electro-positive radicals, I examine their compounds with chlorine, bromine, and iodine. Those electro-negative radicals which form a molecule with a single atom of hydrogen are monatomic; those which combine with 2 of hydrogen are biatomic, and so on. Conversely, the electro-positive radicals are monatomic if they combine with a single atom of halogen, biatomic if they combine with 2.

With these rules I establish—

1°. That cyanogen, CN, is a monatomic electro-negative radical, and that the molecule of free cyanogen contains twice the quantity of carbon and nitrogen contained in the molecule of the monocyanides; and that in this way cyanogen, CN, behaves in all respects like an atom of chlorine, Cl;

2°. That cacodyle, C^2H^6As, methyl, CH^3, ethyl, C^2H^5, and the other homologous and isologous radicals, are, like the atom of hydrogen, monatomic, and like it cannot form a molecule alone, but must associate

themselves with another monatomic radical, simple or compound, whether of the same or of a different kind;

3°. That ethylene, C^2H^4, propylene, C^3H^6, are biatomic radicals analogous to the radicals of mercuric and cupric salts, and to those of the salts of zinc, lead, calcium, magnesium, etc.; and that these radicals, like the atom of mercury, can form a molecule by themselves.

The analogy between the mercuric salts and those of ethylene and propylene has not been noted, so far as I know, by any other chemist. All that I have expounded previously shows it with such clearness that it appears useless to stop and discuss it with you at length. In fact, just as 1 volume of the vapour of mercury, combining with an equal volume of chlorine, makes 1 volume of vapour of mercury bichloride, so 1 volume of ethylene combined with an equal volume of chlorine makes a single volume of vapour of chloride of ethylene—(oil of Dutch chemists). If the formula of this last is $C^2H^4Cl^2$, that of bichloride of mercury should be $HgCl^2$; and if this is the formula of the bichloride of mercury, the chlorides of zinc, lead, calcium, etc., must also be MCl^2; that is, the atoms of all these metals are, like ethylene and propylene, biatomic radicals. Observing that all the electro-positive monatomic radicals which can be weighed free in the gaseous state, behave like hydrogen, that is, cannot of themselves form molecules, it appears to me very probable that a capacity of saturation equal to that of hydrogen in atoms, or groups which can act as their substitutes, constantly coincides with the fact of their not being able to exist in the isolated state. This is the reason why, until there is proof to the contrary, I believe that the molecules of

potassium, sodium, lithium, and silver in the free state are formed of two atoms, that is, are represented by the formulæ K^2, Na^2, Li^2, Ag^2.

Conversely, observing that if the atom of mercury (which tends to form a biatomic rather than a monatomic radical) like ethylene and propylene can exist in the free state, forming a distinct molecule by itself, it appears to me probable that the atoms of zinc, lead, and calcium should be endowed also with this property, that is, that the molecules of these metals should consist of a single atom. If this correspondence between the number of atoms contained in the molecule and the capacity of the saturation of the atom, or of the group which takes its place, is verified, we may sum up as follows: *the metallic radicals whose molecules enter as a whole into compounds are biatomic, those whose atom is half a molecule are monatomic.* You already perceive the importance of this correlation, which forces us to conclude that one molecule of mercury (in mercuric salts), or of zinc, or ethylene, or propylene, etc., is equivalent to a molecule of hydrogen, of potassium, or of silver; thus the former as well as the latter combines with an entire molecule of chlorine, yet with this important difference that the former, not being capable of division, forms a single molecule with two atoms of chlorine, whilst the latter, being divisible, makes with the two atoms of chlorine two distinct molecules. But before drawing a general conclusion of such importance, it is necessary to demonstrate somewhat better the accuracy of the data on which it is founded.

In the eighth lecture I begin to compare the mode of behaviour in some reactions of monatomic and biatomic radicals. The compound radicals indicated in the preceding lecture, since they form volatile com-

pounds, frequently afford the means of explaining by analogy what holds good for metallic compounds, the molecular weights of which cannot often be determined directly, since few of them are volatile. This is the great benefit which the study of organic chemistry has rendered to chemistry in general.

In the use of formulæ I adhere to the following rules, which I state before representing by means of equations the various types of reaction :—

1°. I use the coefficients of the symbols in the position of the exponents only when I wish to express that the number of atoms indicated is contained in one and the same molecule ; in other cases I place the coefficient before the symbols. Thus, when I wish to indicate two atoms of free hydrogen as they are contained in a single molecule, I write H^2. If, however, I wish to indicate four atoms as they are contained in two molecules, I do not write H^4 but $2H^2$; for the same reason I indicate *n* atoms of free mercury by the formula *n*Hg.

2°. Sometimes I repeat in the same formula more than once the same symbol to indicate some difference between one part and another of the same element. Thus I write acetic acid $C^2H^3HO^2$, to indicate that one of the four atoms of hydrogen contained in the molecule is in a state different from the other three, it alone being replaceable by metals. Occasionally I write the same symbol several times to indicate several atoms of the same element, only to place better in relief what occurs in some reactions.

3°. For this last reason I often write the various atoms of the same component or the residues of various equal molecules in vertical lines. Thus, for example, I indicate the molecule of bichloride of

mercury, $HgCl^2$, as follows:—$Hg \left\{ \begin{matrix} Cl \\ Cl \end{matrix} \right.$; the molecule of acetate of mercury, $C^4H^6HgO^4$, as follows: $Hg \left\{ \begin{matrix} C^2H^3O^2 \\ C^2H^3O^2 \end{matrix} \right.$; to indicate that the two atoms of chlorine or the two residues of acetic acid come from two distinct molecules of hydrochloric acid and of hydrated acetic acid.

4°. I indicate by the symbol R^{i}_{m} any monatomic metallic radical whether simple or compound; and with the symbol R^{ii}_{m} any biatomic metallic radical. If in the same formula or in the same equation I wish to indicate in general two or more monatomic radicals, the one different from the other, I add to the symbol the small letters *a*, *b*, *c*, etc., thus R^{i}_{ma} R^{i}_{mb} indicates a single molecule formed of two different monatomic radicals; such are the so-called mixed radicals.

The molecules of the monatomic metallic radicals are represented by the formula $(R^{i}_{m})^2$; those of the biatomic radicals by the same symbol as for the radical existing in its compounds, since it is the character of these radicals to have the molecule formed of a single atom or of a single group which takes its place. You understand that in speaking of metallic radicals I include all those which can replace metals in saline compounds.

5°. Since all compounds containing in their molecule a single atom of hydrogen replaceable by metals behave similarly when they act on metals or on their compounds, it is convenient to adopt a general formula, and I shall use the following. In HX, X indicates all that there is in the molecule except metallic hydrogen; thus, for example, in the case of acetic acid, $X = C^2H^3O^2$, these being the components which to-

gether with H make up the molecule of hydrated acetic acid. Since there are compounds, also called acids, whose molecules contain two atoms of hydrogen replaceable by metals, and since owing to this last fact they behave in a similar manner towards molecules containing metals, I adopt for them the general formula H^2Y, indicating by Y all that there is in the molecules except the two atoms of hydrogen. I hasten to mention that when I indicate by X and by Y the things which in the molecules of acids are combined with H and H^2, I do not intend to affirm that X and H, or Y and H^2, are detached within the molecule as its two immediate components; but without touching the question of the disposition of the atoms within the molecule of acids, I only wish to indicate distinctly the part which is not changed in the transformation of the acid into its corresponding salts.

Before treating and discussing the various reactions, I remind my pupils once more that all the formulæ used by me correspond to equal gaseous volumes, the theory of Avogadro and Ampère being constantly the guiding thread which leads me in the study of chemical reactions.

This done, I now give very rapidly an abstract of what I explain in this lecture concerning some reactions of the monatomic and biatomic radicals. I always write the reaction of the molecule containing a monatomic radical alongside a corresponding one of a molecule containing a biatomic radical, in order that the comparison may be easier.

Direct Combination	
Of the Monatomic Metallic Radicals with the Halogens.	Of the Biatomic Metallic Radicals with the Halogens.
$*H^2 + Cl^2 = 2\,HCl$ 1 molecule of hydrogen. 1 molecule of chlorine. 2 molecules of hydrochloric acid.	$Hg + Cl^2 = HgCl^2$ 1 molecule of mercury. 1 molecule of chlorine. 1 molecule of bichloride of mercury.
$K^2 + Cl^2 = 2\,KCl$ 1 molecule of potassium. 1 molecule of chlorine. 2 molecules of chloride of potassium.	$Zn + Cl^2 = ZnCl^2$ 1 molecule of zinc. 1 molecule of chlorine. 1 molecule of chloride of zinc.
$\dagger(CH^3)^2 + Cl^2 = 2\,CH^3Cl$ 1 molecule of methyl. 1 molecule of chlorine. 2 molecules of chloride of methyl.	$C^2H^4 + Cl^2 = C^2H^4Cl^2$ 1 molecule of ethylene. 1 molecule of chlorine. 1 molecule of chloride of ethylene.
$(R^{i}_{m})^2 + Cl^2 = 2\,R^{i}_{m}Cl$	$R^{ii}_{m} + Cl^2 = R^{ii}_{m}Cl^2$
Apparent direct combination, in reality molecular double decomposition, in virtue of which two molecules of different kinds give two of the same kind.	True direct combination or union of two different entire molecules into a single molecule.

* The direct combination of hydrogen and chlorine is expressed by some as $H + Cl = HCl$; in the equations used by me I always employ molecules.

† It appears that in practice this direct combination succeeds with difficulty, the chlorine having an action on the hydrogen of the radical; it has been indicated merely for comparison with that of ethylene.

From what precedes it may be observed that a complete molecule of chlorine, and thus of any halogen, always reacts with a complete molecule of a metallic radical; if the latter is monatomic it makes two molecules, if it is biatomic it forms only one.

SUBSTITUTIONS IN CHLORIDES, BROMIDES, AND IODIDES

Of one Monatomic Metallic Radical for another.							Of one Biatomic Metallic Radical for a Monatomic.						
K^2	+	$\begin{matrix}HCl\\HCl\end{matrix}$	=	H^2	+	$\begin{matrix}KCl\\KCl\end{matrix}$	Zn	+	$\begin{matrix}HCl\\HCl\end{matrix}$	=	H^2	+	$Zn\left\{\begin{matrix}Cl\\Cl\end{matrix}\right.$
1 molecule of potassium.		2 molecules of hydrochloric acid.		1 molecule of hydrogen.		2 molecules of chloride of potassium.	1 molecule of zinc.		2 molecules of hydrochloric acid.		1 molecule of hydrogen.		1 molecule of chloride of zinc.
H^2	+	$\begin{matrix}AgCl\\AgCl\end{matrix}$	=	Ag^2	+	$\begin{matrix}HCl\\HCl\end{matrix}$	Zn	+	$\begin{matrix}AgCl\\AgCl\end{matrix}$	=	Ag^2	+	$Zn\left\{\begin{matrix}Cl\\Cl\end{matrix}\right.$
1 molecule of hydrogen.		2 molecules of chloride of silver.		1 molecule of silver.		2 molecules of hydrochloric acid.	1 molecule of zinc.		2 molecules of chloride of silver.		1 molecule of silver.		1 molecule of chloride of zinc.
Ag^2	+	$\begin{matrix}HI\\HI\end{matrix}$	=	H^2	+	$\begin{matrix}AgI\\AgI\end{matrix}$	Hg	+	$\begin{matrix}HI\\HI\end{matrix}$	=	H^2	+	$Hg\left\{\begin{matrix}I\\I\end{matrix}\right.$
1 molecule of silver.		2 molecules of hydriodic acid.		1 molecule of hydrogen.		2 molecules of iodide of silver.	1 molecule of mercury.		2 molecules of hydriodic acid.		1 molecule of hydrogen.		1 molecule of biniodide of mercury.
$(R^{i}_{ma})^2$	+	$\begin{matrix}R^{i}_{mb}Cl\\R^{i}_{mb}Cl\end{matrix}$	=	$(R^{i}_{mb})^2$	+	$\begin{matrix}R^{i}_{ma}Cl\\R^{i}_{ma}Cl\end{matrix}$	R^{ii}_{m}	+	$\begin{matrix}R^{i}_{m}Cl\\R^{i}_{m}Cl\end{matrix}$	=	$(R^{i}_{m})^2$	+	$R^{ii}_{m}\left\{\begin{matrix}Cl\\Cl\end{matrix}\right.$
Substitution without change in the number of molecules.							Substitution with change in the number of molecules; 3 become 2.						

From what is written in this table it is seen that two molecules of hydrochloric acid or of another analogous monochloride always react with a single molecule of metallic radical; if this is monatomic, they change into two molecules of monochloride, if it is biatomic into a single molecule of bichloride. The cause of the last difference consists in this: that the molecule of the monatomic radical is divisible into two; that of the biatomic radical, not being capable of division, collects into a single molecule the residues of two molecules of monochloride or monoiodide.

The biatomic radicals behave similarly to the acids containing 1 atom of monatomic metallic radicals (H, Ag, K); collecting into a single molecule the residues of two molecules of acids or of salts, as may be seen in the following comparative table.

[TABLE

SUBSTITUTION IN THE ACIDS HX, AND IN GENERAL IN THE SALTS $R^{i}_{m}X$,

Of a Monatomic Metallic Radical, R^{i}_{ma}, for another, R^{i}_{mb}.							Of a Biatomic Metallic Radical, R^{ii}_{m}, for a Monatomic, R^{i}_{m}.						
K^2	+	$HAzO^3$ $HAzO^3$	=	H^2	+	$KAzO^3$ $KAzO^3$	Zn	+	$HAzO^3$ $HAzO^3$	=	H^2	+	$Zn\begin{cases}AzO^3\\AzO^3\end{cases}$
1 molecule of potassium.		2 molecules of hydrated nitric acid.		1 molecule of hydrogen.		2 molecules of nitrate of potassium.	1 molecule of zinc.		2 molecules of hydrated nitric acid.		1 molecule of hydrogen.		1 molecule of nitrate of zinc.
Na^2	+	$HC^2H^3O^2$ $HC^2H^3O^2$	=	H^2	+	$NaC^2H^3O^2$ $NaC^2H^3O^2$	Zn	+	$HC^2H^3O^2$ $HC^2H^3O^2$	=	H^2	+	$Zn\begin{cases}C^2H^3O^2\\C^2H^3O^2\end{cases}$
1 molecule of sodium.		2 molecules of hydrated acetic acid.		1 molecule of hydrogen.		2 molecules of acetate of sodium.	1 molecule of zinc.		2 molecules of hydrated acetic acid.		1 molecule of hydrogen.		1 molecule of acetate of zinc.
$(R^{i}_{ma})^2$	+	$R^{i}_{mb}X$ $R^{i}_{mb}X$	=	$(R^{i}_{mb})^2$	+	$R^{i}_{ma}X$ $R^{i}_{ma}X$	R^{ii}_{m}	+	$R^{i}_{m}X$ $R^{i}_{m}X$	=	$(R^{i}_{m})^2$	+	$R^{ii}_{m}\begin{cases}X\\X\end{cases}$

These examples are sufficient to show that the compounds containing a monatomic metallic radical behave like the monochlorides: two molecules of these react with a single molecule of metallic radical, changing into two molecules if the latter is monatomic, into a single molecule if it is biatomic. We can prove more easily that the biatomic metallic radicals bind in a single molecule the residues X of two molecules $R^{i}_{m}X$, by comparing the double decompositions or mutual substitutions of the chlorides of the monatomic and biatomic radicals with the compound $R^{i}_{m}X$.

I write in the following table some examples of these double decompositions.

[TABLE

MUTUAL SUBSTITUTION OF THE COMPOUNDS CONTAINING A MONATOMIC RADICAL, $R^{i}_{m}X$,

With the Chlorides of the Monatomic Metallic Radicals $R^{i}_{m}Cl$.				With the Chlorides of the Biatomic Metallic Radicals $R^{ii}_{m}Cl^{2} = R^{ii}_{m}\left\{\begin{matrix}Cl\\Cl\end{matrix}\right.$			
KCl	$+\ HAzO^{3}$	$=\ HCl$	$+\ KAzO^{3}$	$Hg\left\{\begin{matrix}Cl\\Cl\end{matrix}\right.$	$+\ \begin{matrix}HAzO^{3}\\HAzO^{3}\end{matrix}$	$=\ \begin{matrix}HCl\\HCl\end{matrix}$	$+\ Hg\left\{\begin{matrix}AzO^{3}\\AzO^{3}\end{matrix}\right.$
1 molecule of chloride of potassium.	1 molecule of hydrated nitric acid.	1 molecule of hydrochloric acid.	1 molecule of nitrate of potassium.	1 molecule of bichloride of mercury.	2 molecules of hydrated nitric acid.	2 molecules of hydrochloric acid.	1 molecule of mercuric nitrate.
KCl	$+\ AgC^{2}H^{3}O^{2}$	$=\ AgCl$	$+\ KC^{2}H^{3}C^{2}$	$Hg\left\{\begin{matrix}Cl\\Cl\end{matrix}\right.$	$+\ \begin{matrix}AgC^{2}H^{3}O^{2}\\AgC^{2}H^{3}O^{2}\end{matrix}$	$=\ \begin{matrix}AgCl\\AgCl\end{matrix}$	$+\ Hg\left\{\begin{matrix}C^{2}H^{3}O^{2}\\C^{2}H^{3}O^{2}\end{matrix}\right.$
1 molecule of chloride of potassium.	1 molecule of acetate of silver.	1 molecule of chloride of silver.	1 molecule of acetate of potassium.	1 molecule of bichloride of mercury.	2 molecules of acetate of silver.	2 molecules of chloride of silver.	1 molecule of mercurie acetate.
$C^{2}H^{5}, Cl$	$+\ AgC^{2}H^{3}O^{2}$	$=\ AgCl$	$+\ C^{2}H^{5}, C^{2}H^{3}O^{2}$	$C^{2}H^{4}\left\{\begin{matrix}Cl\\Cl\end{matrix}\right.$	$+\ \begin{matrix}AgC^{2}H^{3}O^{2}\\AgC^{2}H^{3}O^{2}\end{matrix}$	$=\ \begin{matrix}AgCl\\AgCl\end{matrix}$	$+\ C^{2}H^{5}\left\{\begin{matrix}C^{2}H^{3}O^{2}\\C^{2}H^{3}O^{2}\end{matrix}\right.$
1 molecule of chloride of ethyl.	1 molecule of acetate of silver.	1 molecule of chloride of silver.	1 molecule of acetate of ethyl.	1 molecule of chloride of ethylene.	2 molecules of acetate of silver.	2 molecules of chloride of silver.	1 molecule of acetate of ethylene.
R^{i}_{ma}, Cl	$+\ R^{i}_{mb}X$	$=\ R^{i}_{mb}Cl$	$+\ R^{i}_{ma}X$	$R^{ii}_{m}\left\{\begin{matrix}Cl\\Cl\end{matrix}\right.$	$+\ \begin{matrix}R^{i}_{m}, X\\R^{i}_{m}, X\end{matrix}$	$=\ \begin{matrix}R^{i}_{m}Cl\\R^{i}_{m}Cl\end{matrix}$	$+\ R^{ii}_{m}\left\{\begin{matrix}X\\X\end{matrix}\right.$

All the reactions indicated in this table may be summed up as follows :—Whatever is combined with one atom of hydrogen or any other equivalent radical =(X) replaces one atom of chlorine, and conversely is replaceable by the latter ; if an indivisible radical in the double decompositions is found combined in a single molecule with two atoms of chlorine, it will, if the chlorine is exchanged for X, remain combined in a single molecule with 2X.

That ethylene is combined with two atoms of chlorine in choride of ethylene, and that the acetate of ethylene contains in one molecule twice $C^2H^3O^2$, is shown by the comparison of the gaseous densities of these substances. From the vapour density and from the specific heats, it is further demonstrated that the molecule of corrosive sublimate, like that of chloride of ethylene, contains two atoms of chlorine. Hence the mercuric salts are constituted in a similar manner to those of ethylene, whilst the salts of potassium, sodium, and silver are formed like those of ethyl.

Having proved, then, as I think I have already sufficiently indicated, that the lower or only chlorides of iron, manganese, zinc, magnesium, calcium, barium, etc., are constituted like corrosive sublimate, that is, have the formula MCl^2, there can remain no further doubt that the salts which are obtained by means of these chlorides and of the monobasic acids, or of their salts, are all similar to those of ethylene, propylene, etc. These important conclusions may be summed up as follows :—

1°. Amongst the salts of monobasic acids only those of hydrogen, potassium, sodium, lithium, silver, together with mercurous and cuprous salts, are similar to those of methyl and ethyl, that is, to compounds

of the alcohols containing a monatomic radical; all the other salts, of the so-called protoxides, are similar to those of ethylene and propylene, that is, to the compound ethers of the alcohols with biatomic radicals.

2°. A single molecule of the first is not sufficient to form the anhydrous acid and the metallic oxide; two molecules instead are required; but a single molecule of the second contains the components of the molecule of the anhydrous acid and of that of the protoxide. This becomes clear by bringing the following equations into comparison :—

$\begin{matrix} AgC^2H^3O^2 \\ AgC^2H^3O^2 \end{matrix} = \left.\begin{matrix} Ag \\ Ag \end{matrix}\right\} O + C^4H^6O^3$	$Hg\left\{\begin{matrix} C^2H^3O^2 \\ C^2H^3O^2 \end{matrix}\right. = HgO + C^4H^6O^3$
2 molecules of acetate of silver. — 1 molecule of oxide of silver. — 1 molecule of anhydrous acetic acid.	1 molecule of mercuric acetate. — 1 molecule of oxide of mercury. — 1 molecule of anhydrous acetic acid.
$\begin{matrix} C^2H^5, C^2H^3O^2 \\ C^2H^5, C^2H^3O^2 \end{matrix} = \left.\begin{matrix} C^2H^5 \\ C^2H^5 \end{matrix}\right\} O + C^4H^6O^3$	$C^2H^4\left\{\begin{matrix} C^2H^3O^2 \\ C^2H^3O^2 \end{matrix}\right. = C^2H^4O + C^4H^6O^3$
2 molecules of acetate of ethyl. — 1 molecule of oxide of ethyl. — 1 molecule of anhydrous acetic acid.	1 molecule of acetate of ethylene. — 1 molecule of oxide of ethylene. — 1 molecule of anhydrous acetic acid.
$\begin{matrix} R^i_mX \\ R^i_mX \end{matrix} = \left.\begin{matrix} R^i_m \\ R^i_m \end{matrix}\right\} O + (2X - O)$	$R^{ii}_m\left\{\begin{matrix} X \\ X \end{matrix}\right. = R^{ii}_mO + (2X - O)$

The mercuric salts and the salts of zinc, etc., being similar to those of ethylene, it is probable that salts of this type exist containing the residues of two different monobasic acids. I indicate by what reactions they might be generated :—

$Hg\left\{\begin{matrix}Cl\\Cl\end{matrix}\right.$ +	$\begin{matrix}AgC^2H^3O^2\\AgC^2H^3O^2\end{matrix}$ =	$\begin{matrix}AgCl\\AgCl\end{matrix}$ +	$Hg\left\{\begin{matrix}C^2H^3O^2\\C^2H^3O^2\end{matrix}\right.$
1 molecule of bichloride of mercury.	2 molecules of acetate of silver.	2 molecules of chloride of silver.	1 molecule of acetate of mercury.
$Hg\left\{\begin{matrix}Cl\\Cl\end{matrix}\right.$ +	$\begin{matrix}AgC^2H^3O^2\\AgC^7H^5O^2\end{matrix}$ =	$\begin{matrix}AgCl\\AgCl\end{matrix}$ +	$Hg\left\{\begin{matrix}C^2H^3O^2\\C^7H^5O^2\end{matrix}\right.$
1 molecule of bichloride of mercury.	1 molecule of acetate and 1 of benzoate of silver.	2 molecules of chloride of silver.	1 molecule of benzacetate of mercury.
$C^2H^4\left\{\begin{matrix}Cl\\Cl\end{matrix}\right.$ +	$\begin{matrix}AgC^2H^3O^2\\AgC^7H^5O^2\end{matrix}$ =	$\begin{matrix}AgCl\\AgCl\end{matrix}$ +	$C^2H^4\left\{\begin{matrix}C^2H^3O^2\\C^7H^5O^2\end{matrix}\right.$
1 molecule of chloride of ethylene.	1 molecule of acetate and 1 of benzoate of silver.	2 molecules of chloride of silver.	1 molecule of benzacetate of ethylene.

Just as acetates are produced from anhydrous acetic acid and the oxides of biatomic metallic radicals, so from anhydrous benzacetic acid the benzacetates will be formed, as I indicate in the following equation :—

$$C^4H^6O^3 + R^{ii}_{m}O = R^{ii}_{m}C^4H^6O^4 = R^{ii}_{m}\left\{\begin{matrix}C^2H^3O^2\\C^2H^3O^2\end{matrix}\right.$$

$$C^9H^8O^3 + R^{ii}_{m}O = R^{ii}_{m}C^9H^8O^4 = R^{ii}_{m}\left\{\begin{matrix}C^2H^3O^2\\C^7H^5O^2\end{matrix}\right.$$

Having already proved that zinc is a biatomic radical, and that in consequence its atomic weight should be doubled, I stop to examine the reactions and the mode of formation of zinc ethyl, zinc methyl, etc. I show you by means of equations the method by which I interpret these reactions.

The vapour densities demonstrate the accuracy of the following formulæ corresponding to equal volumes : — C^2H^5Cl (chloride of ethyl) C^2H^5, H (hydride of ethyl) C^2H^5, C^2H^5 (free ethyl) C^2H^5, CH^3 (methyl ethyl), $Zn(C^2H^5)^2 = Zn\left\{\begin{matrix}C^2H^5\\C^2H^5\end{matrix}\right.$ (zinc ethyl).

$$C^2H^5Cl + H^2 = C^2H^5, H + HCl$$

$$\begin{matrix} C^2H^5Cl \\ C^2H^5Cl \end{matrix} + Zn = (C^2H^5)^2 + Zn\left\{\begin{matrix} Cl \\ Cl \end{matrix}\right.$$

$$\begin{matrix} C^2H^5Cl \\ C^2H^5Cl \end{matrix} + 2Zn = \left.\begin{matrix} C^2H^5 \\ C^2H^5 \end{matrix}\right\} Zn + Zn\left\{\begin{matrix} Cl \\ Cl \end{matrix}\right.$$

$$\begin{matrix} C^2H^5Cl \\ C^2H^5Cl \end{matrix} + \left.\begin{matrix} C^2H^5 \\ C^2H^5 \end{matrix}\right\} Zn = 2(C^2H^5)^2 + Zn\left\{\begin{matrix} Cl \\ Cl \end{matrix}\right.$$

$$\begin{matrix} C^2H^5Cl \\ CH^3Cl \end{matrix} + Zn = C^2H^5, CH^3 + Zn\left\{\begin{matrix} Cl \\ Cl \end{matrix}\right.$$

$$\begin{matrix} C^2H^5Cl \\ CH^3Cl \end{matrix} + 2Zn = \left.\begin{matrix} C^2H^5 \\ CH^3 \end{matrix}\right\} Zn + Zn\left\{\begin{matrix} Cl \\ Cl \end{matrix}\right.$$

No one has yet demonstrated, as far as I know, the existence of the type of compound indicated in the last equation. But it being proved from the density of zinc ethyl vapour, and from its specific heat, that the complete molecule of zinc ethyl contains a single atom of zinc combined with two ethyl radicals, that is, with the molecule of the free radical, no one can deny that there will be prepared compounds containing a single atom of zinc combined with two different monatomic radicals. It may also be predicted that ethylene and propylene will form compounds in whose molecules an atom of zinc is combined with the biatomic radical.

I will give you later an account of some of my experiments directed to show the existence of the compounds just mentioned.

After having spoken of the mode of behaviour of the compounds containing monatomic or biatomic radicals with regard to monobasic acids, I examine the mode of behaviour with regard to those compounds which contain in each molecule two atoms of hydrogen, or, as they are called, the bibasic acids, to which I have given the general formula H^2Y.

To predict the reactions, it is sufficient to bear in mind what follows :—

1°. The two atoms of hydrogen are united in a single molecule by the forces of all the other components which together we call Y, hence what is equivalent to H^2 can enter into a single molecule with Y.

2°. What is combined with H^2 is equivalent to two atoms of chlorine Cl^2; hence in double decomposition H^2Y will act either on a single molecule of a bichloride ($=R^{ii}_{m}Cl^2$) or on two molecules of a monochloride; what is combined with two atoms of chlorine, whether in one or in two molecules, will combine with Y; and H^2 combining with Cl^2 will always form two molecules of hydrochloric acid.

The examples of double decomposition which follow clearly show what I have just indicated.

Double Decompositions of Hydrated Sulphuric Acid, H^2SO^4,	
With the Monochlorides $R^{ii}_{m}Cl$.	With the Bichlorides $R^{ii}_{m}Cl^2$.
$\begin{matrix}NaCl\\NaCl\end{matrix} + H^2SO^4 = \begin{matrix}HCl\\HCl\end{matrix} + Na^2SO^4$	$Hg\left\{\begin{matrix}Cl\\Cl\end{matrix}\right. + H^2SO^4 = \begin{matrix}HCl\\HCl\end{matrix} + HgSO^4$
$\begin{matrix}NaCl\\NaCl\end{matrix} + Ag^2SO^4 = \begin{matrix}AgCl\\AgCl\end{matrix} + Na^2SO^4$	$Hg\left\{\begin{matrix}Cl\\Cl\end{matrix}\right. + Ag^2SO^4 = \begin{matrix}AgCl\\AgCl\end{matrix} + HgSO^4$
$\begin{matrix}C^2H^5Cl\\C^2H^5Cl\end{matrix} + Ag^2SO^4 = \begin{matrix}AgCl\\AgCl\end{matrix} + (C^2H^5)^2SO^4$	$C^2H^4\left\{\begin{matrix}Cl\\Cl\end{matrix}\right. + Ag^2SO^4 = \begin{matrix}AgCl\\AgCl\end{matrix} + C^2H^4SO^4$

In connection with this point I compare the formulæ of the oxy-salts proposed by me with those of Berzelius and of Gerhardt, and discuss the causes of the

differences and of the coincidences, which may be summed up as follows :—

1°. All the formulæ given by Berzelius to the oxy-salts of the biatomic metallic radicals are the same as those proposed by me, whether the acid is monobasic or bibasic ; all these oxy-salts contain in each molecule the elements of a complete molecule of oxide and of a complete molecule of anhydrous acid.

2°. There correspond also to the formulæ proposed by me all those of Berzelius for sulphates and analogous salts, if we introduce the modification by Regnault, *i.e.*, if we consider the quantity of metal contained in the molecules of potassic, argentic, mercurous, and cuprous sulphates equal to 2 atoms, and those on the other hand of metal contained in the molecules of mercuric, cupric, plumbic, zincic, calcic, baric, etc., sulphates, equal to a single atom.

3°. The formulæ proposed by me for the oxy-salts of potassium, sodium, silver, hydrogen, methyl, and all the other analogous monatomic radicals with a monobasic acid, are equal to half the formulæ proposed by Berzelius and modified by Regnault, *i.e.*, each molecule of them contains the components of half a molecule of anhydrous acid and half a molecule of metallic oxide.

4°. The formulæ of Gerhardt coincide with those proposed by me only for the salts of potassium, sodium, silver, hydrogen, methyl, and all the other monatomic radicals, but not for those of zinc, lead, calcium, barium, and the other metallic protoxides ; Gerhardt having wished to consider all the metals analogous to hydrogen, which I have shown to be erroneous.

In the succeeding lectures I speak of the oxides with monatomic and biatomic radicals, afterwards I treat

of the other classes of polyatomic radicals, examining comparatively the chlorides and the oxides; lastly, I discuss the constitution of acids and of salts, returning with new proofs to demonstrate what I have just indicated.

But of all this I will give you an abstract in another letter.

GENOA, 12*th March* 1858.

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